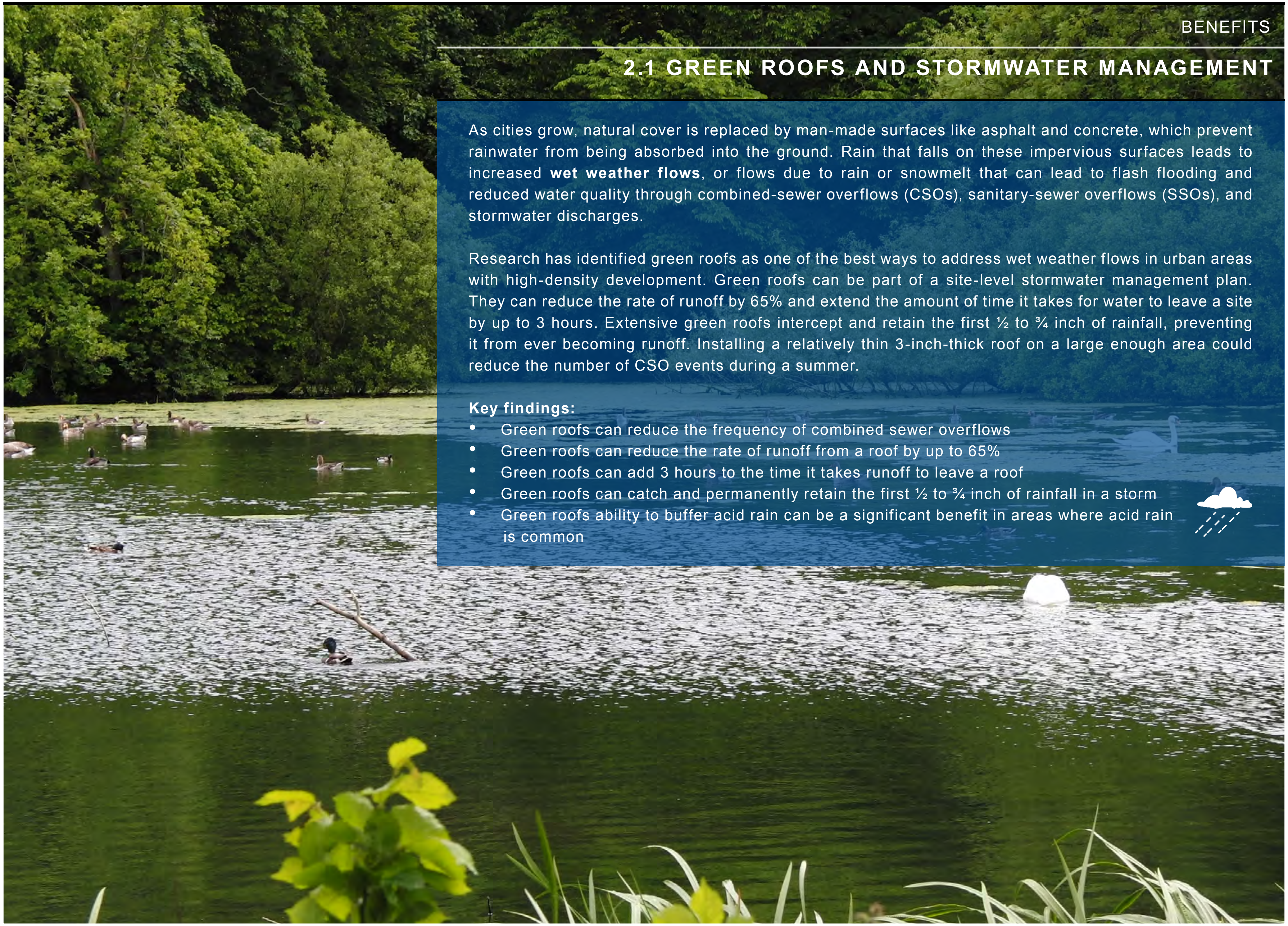
2.0 BENEFITS

Green roofs offer economic, environmental, and societal benefits for the individual building and the wider urban environment. These benefits range from stormwater management impacts on local infrastructure to amenity benefits for building occupants and the community.

This chapter categorizes the main benefits of green roof installation under the following focus areas:

- Stormwater management
- Biodiversity and habitat
- Urban heat island
- Energy
- Urban agriculture
- Acoustics
- Air quality
- Aesthetics and quality of life
- Job generation and economic development
- Roof longevity

Each focus area presents a brief background on the importance of the topic area, and discusses and analyzes the benefits of green roofs in regards to that issue.



2.1 GREEN ROOFS AND STORMWATER MANAGEMENT

As cities grow, natural cover is replaced by man-made surfaces like asphalt and concrete, which prevent rainwater from being absorbed into the ground. Rain that falls on these impervious surfaces leads to increased **wet weather flows**, or flows due to rain or snowmelt that can lead to flash flooding and reduced water quality through combined-sewer overflows (CSOs), sanitary-sewer overflows (SSOs), and stormwater discharges.

Research has identified green roofs as one of the best ways to address wet weather flows in urban areas with high-density development. Green roofs can be part of a site-level stormwater management plan. They can reduce the rate of runoff by 65% and extend the amount of time it takes for water to leave a site by up to 3 hours. Extensive green roofs intercept and retain the first ½ to ¾ inch of rainfall, preventing it from ever becoming runoff. Installing a relatively thin 3-inch-thick roof on a large enough area could reduce the number of CSO events during a summer.

Key findings:

- Green roofs can reduce the frequency of combined sewer overflows
- Green roofs can reduce the rate of runoff from a roof by up to 65%
- Green roofs can add 3 hours to the time it takes runoff to leave a roof
- Green roofs can catch and permanently retain the first ½ to ¾ inch of rainfall in a storm
- Green roofs ability to buffer acid rain can be a significant benefit in areas where acid rain is common

2.1.1 Introduction

Increased wet weather flows are of particular concern in areas with combined sewer systems, such as Washington DC. The Chesapeake Bay Foundation Scientific and Technical Advisory Committee projects that the area of developed land in the capitol region will grow by more than 60% over the next 20 years, suggesting that the region's drainage challenges will also continue to increase.

Stormwater can be managed in a number of ways to reduce the problems of stormwater runoff, especially sewer overflows and their impact on water quality. These can be divided into two primary groups:

- **Low-impact development (LID)**, a sustainable landscaping approach used to replicate or restore natural watershed functions and address targeted watershed goals and objectives, and
- **End-of-pipe best management practices (BMPs)**, or methods found to be the most effective, practical means of preventing or reducing pollution from non-point sources.

Unlike most other LID and structural BMPs, green roofs reduce runoff rates for both large and small storms.

Low-impact development aims to reduce total runoff, delay or reduce the maximum rate of runoff, and to filter out and detain pollutants. Green roofs are one example of a low-impact development technology that can help planners achieve each of these objectives. Research has also identified them as one of the best ways to address wet weather flows in urban areas with high-density development. Other low-impact development methods of addressing water overflows include cisterns, biofiltration systems, filter strips, expanded tree box planters and permeable pavements.*

This section addresses the identified benefits of green roofs in terms of:

- Slowing and retaining stormwater, and
- Reducing the level of pollutants in stormwater

Permeable pavements (left) and biofiltration (right)

Water on the green roof is evaporated by solar radiation, condenses and returns to the land as precipitation. Some of the water is stored by the vegetation, on the surface (puddles), or in soil pores, and is eventually evaporated. The remaining water either runs off the surface or infiltrates the green roof, where the water is collected and discharged off the roof.

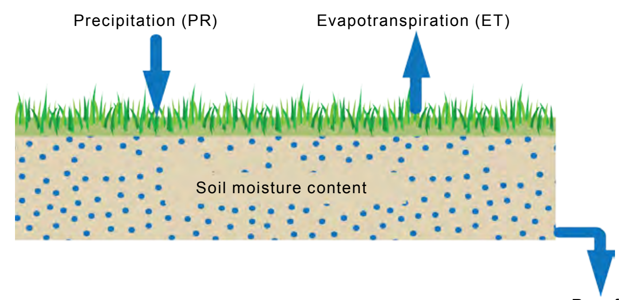


Figure 10: Green roof water budget

*Cisterns and infiltration basins may be installed under the street level, but the stormwater would still have to be discharged in a location other than the storm sewer; this requirement can render them impractical. Narrow bioswales might also be used as ground-level LID BMPs if space permits.

2.1.2 Slowing and Retaining Stormwater

Green roofs in Philadelphia have been shown to retain between 38% and 54% of precipitation with a 3-inch growing medium, or 40% to 50% with a depth of four inches using simulations in other cities. A 2005 study reported retention of over 80%, while retention of nearly all precipitation during summer storms has been reported for roofs as diverse as a 4-inch thick garden shed roof and a 75,000 square foot commercial roof in Chicago.

Preliminary studies in New York City suggest that modular green roofs have lower retention rates than built-in-place systems, due to the effect of tray boundaries on water flow, and of the reduction of growth medium due to spaces between the trays.

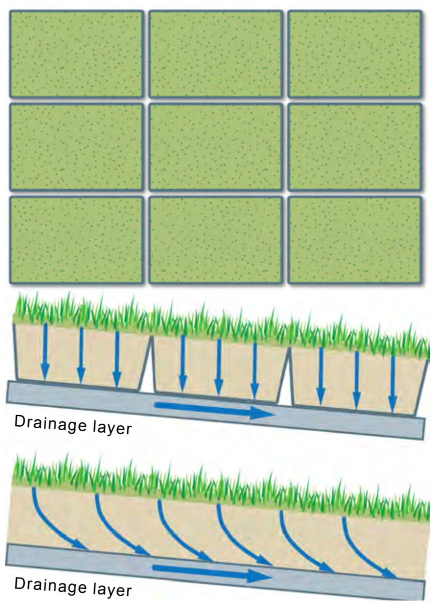


Figure 11: Boundary gaps in modular units (top) and drainage in modular units (middle) create more direct runoff routes than built in-place green roof systems (bottom)

A green roof affects runoff in two primary ways:

1. Increasing the amount of water that remains on a roof after a storm, and
2. Reducing the rate at which water flows from the roof into the sewer system

In contrast, black and white roofs have no effect on slowing or reducing rainwater runoff.

The plants, growth medium and other materials used in a green roof are what allow it to absorb stormwater. A green roof's ability to absorb and retain stormwater depends on a number of factors, including:

- The drainage layer
- The growing medium
- The plants (or vegetation)
- The roof slope
- The season and climate
- The roof size

The configuration of roof layers and the materials used are also important factors. The choice of plants used in a green roof also help maximize the amount of water it retains through the process of evapotranspiration.

Green roofs can reduce the **peak flow rate**, or the maximum rate of runoff, as well as the **time of concentration**, or the time it takes for water to flow from the most distant point on a runoff area to the measurement point. Studies have found that the reduction in the peak flow rate depends on the roof's drainage material and configuration, the growth medium, the roof's size and slope, the intensity and duration of the storm, and how damp the roof was before the storm began.

DRAINAGE LAYER

The type of drainage layer and the type of separation or moisture retention fabrics used in a roof will influence the roof's performance (see Table 3 in *Section* 1 for a more detailed comparison of drainage layers).

Multi-course systems are the most commonly installed green roofs in North America. In these systems, the growth medium covers a separate drainage layer that is typically either:

- a coarse aggregate material like sand, gravel or pebbles, covered with a fabric filter, or
- a synthetic geocomposite layer made of dimpled plastic, stiff filaments, or similar material.

Granular drainage layers like sand and gravel tend to increase retention time and delay the peak runoff. These drainage layers have low transmissivity, meaning they resist horizontal flow of stormwater. In addition, aggregate layers can help plants grow better roots, but are heavier and store less water than geocomposites.

Geocomposites are multi-layered materials made from a combination of synthetic polymer to fulfill a specific function like reducing the pressure of water against a green roof's waterproofing layer, or promoting drainage. Many geocomposite layers can also serve as reservoir sheets, and are designed to store water in addition to providing drainage.

The type of separation fabric used also influences the flow rate in roofs with synthetic geocomposite drainage, since dense materials with low hydraulic permittivity restrict and delay flows into the drainage layer.

GROWING MEDIUM

Germany's FLL Guidelines on green roofs suggest the medium used on a green roof generally retains from 30% to 60% of water by volume when totally saturated with water.

The size of growth medium particles, the types of materials used and the depth of the medium all affect the amount of moisture the medium can retain. Smaller particles have a higher surface area-to-mass ratio and smaller pores, both of which enhances the medium's water retention capacity and capillarity, or its ability to absorb water through the capillary action that draws water into a particle.

As the proportion of organic matter in growth medium increases, so does its water retention capacity. However, too much organic material in a medium can cause it to shrink as the material decomposes. If the organic material contains high levels of nutrient salts, or various phosphorus and nitrogen compounds that have a fertilizing effect, it can even decrease the quality of runoff from the roof.

The thicker the growth medium the more water the roof can absorb, at least up to a point. In general, a thicker roof can be expected to retain more water from an individual storm. A 4-inch roof can typically retain 1 to 1.5 inches of rain. This means that in the summer, when most storms produce less than 1 inch of precipitation, 90% of storms are largely retained.

The depth of growth medium is also a factor in reducing stormwater flow, with deeper layers delaying the peak and reducing the flow more than thinner layers, which was observed on green roofs in Auckland, New Zealand. However, benefits do not depend exclusively on depth, and thinner extensive green roofs yield the greatest benefit-to-cost ratio.

PLANTS

The choice of plants used in a green roof can help maximize the amount of water it retains. The plants on a green roof contribute to its water retention capabilities through the process of **evapotranspiration**). Plants take water up from the growth medium through their roots and release it into the air as vapor. Evapotranspiration rates vary depending on the species and environmental conditions. Choosing plants with higher evapotranspiration rates increases the stormwater absorption rates of a green roof.

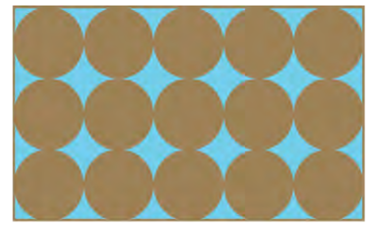
Succulent plants can retain significant amounts of water in their tissues, contributing to the overall storage of water on the roof and to the reduction in annual runoff. Succulents like sedums and *Delosperma* contribute to about 40% of the reduction in runoff attributed to the green roofs they grow in, with the remaining 60% due to evaporation from the growth medium.

To improve the water retention capabilities of a green roof, plants with higher evapotranspiration rates can be used. These typically require deeper growth medium and may also require a supplemental irrigation system to allow them to survive a drought. Irrigation may be needed even in the case of drought-resistant plants like succulents if their potential evapotranspiration rate is greater than the average annual rainfall. Any irrigation system must be carefully managed, as over-watering can reduce the roof's ability to retain stormwater and may reduce the viability of the plants growing on the roof (see *Section* 4.3.2 for over-watering issues).

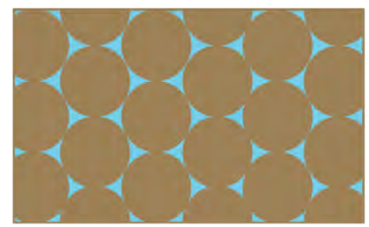
Plants slow runoff in the long-term by taking water up through their roofs, but they can also reduce peak runoff, particularly in the case of broadleaf plants. Plant roots may also allow water to flow horizontally within the growth medium, further reducing runoff.

The stormwater retention properties of a green roof can vary with the season. Typically, green roofs retain far less water in the winter than in the summer, because the growth medium takes longer to dry out or may be frozen, and the plants are less active. In dry climates with mild winters, green roofs are likely to retain more water in the summer than in the winter.

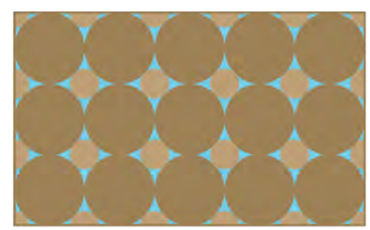
The tightly packed particle distribution (center) retains more water than the loosely packed particle distribution (left). A mixed particle distribution (right) and the addition of organic matter improves retention capacity. Too little pore space may prevent water infiltration.



Loosely packed,
uniform particle size



Tightly packed,
uniform particle size



Tightly packed,
mixed particle size

Figure 12: Particle size distribution in growing medium

As the media depth increases, the amount of the total pore space that is occupied by air at field capacity increases, hence the total moisture retained increases at a slower rate than media depth.

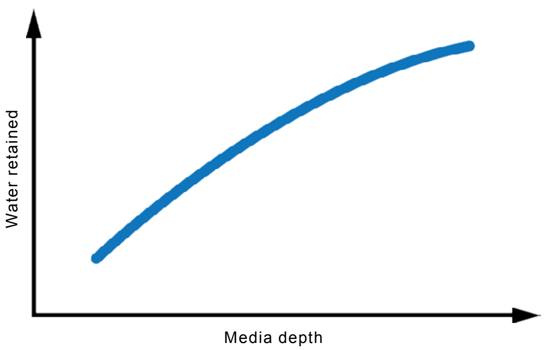


Figure 13: Media depth versus water retained

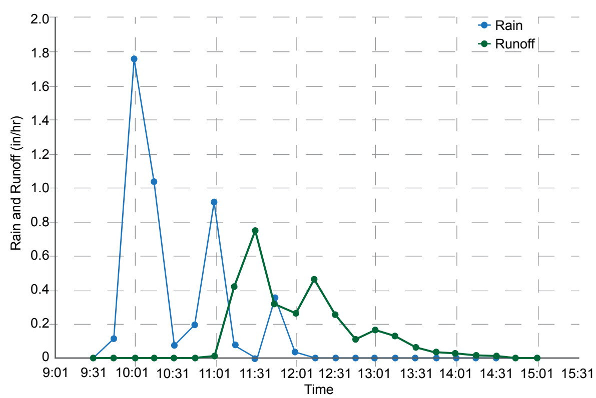


Figure 14: Rainfall and green roof runoff hydrograph from the 75,000 square foot Walmart roof in Chicago for a series of short peaks in June 2009

ROOF SLOPE

The flatter a roof, the greater its water-holding capacity. Sloped roofs also create a number of challenges.

Growth medium on roofs with a pitch of more than 16% will need to be stabilized to keep it in place.

Steep pitches can also create a **moisture gradient**, with the medium on the bottom of the roof typically wetter than that at the top, which may mean plant selection will also need to vary across the roof.

Roof slope has a smaller effect on peak flow rates than vegetation or medium depth. The slope's effect on flow rates depends on the type of drainage layer used. A steeper roof will increase peak flows more in a single-course system or one with restricted drainage than in other types of green roof.† The water retention of a sloped roof can be improved by increasing the depth of the growth medium on the green roof.

SEASON AND STORM ACTIVITY

Green roofs retain the most water in summer months, when plants are active and warm weather boosts evaporation. A 3-inch thick extensive roof on the Gratz factory roof in New York City, monitored by Earth Pledge, recorded seasonal volume reductions of 46% in summer, 35% in fall, 21% in winter, and 39% in spring. Similarly, a 4-inch modular sedum roof on a Con Edison facility in Queens, New York, recorded its highest retention rates during the summer months.

The reduction in the volume of rainwater runoff for any given storm will depend on the amount of rain that falls and how long it has been since the previous storm. The Wal-Mart store in Chicago retained 87% of storms with less than 1 inch of precipitation, and 58% of storms with 1–2 inches during warm months. However, some studies have not seen such clear correlations between total storm depth (the depth of rainfall at a point or over an area) and water retention.

Even a very wet green roof will reduce the peak flow rate of runoff to some extent, but a dry roof will reduce flows to a greater extent. This means that a roof's ability to reduce peak flows will be greater in short storms than in longer ones - as the roof gets more saturated, it will be less able to absorb the rain that falls. Similarly, roofs have a greater effect on peak flow rates in less intense storms. The intensity of a storm has little effect on the total amount of precipitation a green roof retains.

ROOF SIZE

Generally, larger green roofs are better at reducing peak flow rates and the time of runoff concentration than smaller roofs are. For example, the 75,000 square foot green roof on a Walmart in Chicago delays peak runoff for nearly two hours, longer than has been observed with smaller roofs. The non-green section of the roof delayed the peak runoff for 15 minutes or less.

†Flow path in a single-course assembly will be more uniformly within the plane of the green roof; whereas the flow in multi-course assemblies will be dominated by vertical percolation to the drainage layer, after which horizontal flow toward the outlet will be rapid.

2.1.3 Stormwater Pollutant Reduction

Do green roofs reduce the amount of pollutants in stormwater, thereby improving water quality once stormwater drains into lakes and streams? Research provides mixed results. On the positive side, green roofs reduce the volume of stormwater flowing from a roof and therefore the ability of stormwater to convey pollutants to water bodies. They can also neutralize acid rain. However, they can contribute potential **nutrient pollutants** like nitrogen and phosphorous to the runoff from their growth medium and any fertilizer that might be used. When considering the quality of runoff from a green roof, it is important to consider both the concentration and total amount of the pollutants. It is also important to compare the runoff from green roofs to that from black and white roofs, where there is no plant material to affect the chemical content of the rain.

Some studies suggest that green roofs improve the quality of rainwater runoff from roofs, as plants take up potential contaminants from the soil and store them in their tissues. Other studies have found that green roofs actually contribute nutrients to rainwater runoff, which can negatively affect surface water.

> The amount of nutrients in runoff from a green roof depends on the content of the rain, whether fertilizer is used on the roof, and the materials used to produce the growth medium, particularly the compost.

The use of organic materials in the growth medium of green roofs and the application of fertilizer to a roof can also affect the quality of runoff water from the roof.

The definition of which chemicals in stormwater runoff are considered pollutants depends on the characteristics of the **receiving waters** into which the runoff will flow. If they are low on a particular nutrient, its presence in runoff may be seen as beneficial.

NUTRIENTS

Plants need nitrates and phosphorous to survive, but these chemicals can also have negative effects on water quality. Phosphorous and nitrates are added to green roofs as fertilizer. Nitrogen is also found in rainwater, and is added to roofs when rain falls. If roofs are managed to reduce total nutrient impacts, a green roof can have a positive influence on the total amount of nitrogen in rainwater runoff. On the other hand, there is not much phosphorous in rainwater, so green roofs can increase both the concentration and total amount of phosphorous in runoff, as compared with an asphalt roof, as observed on a number of green roofs in Pennsylvania. It should be noted that nutrient loading typically peaks during roof establishment and diminishes after the roof is established.

In a study of green roofs that were managed with minimal application of fertilizer, runoff showed no significant difference in nitrate concentration from rainwater runoff from asphalt roofs. Because the green roofs retained water and reduced the total volume of runoff, they reduced the total mass of nitrogen in the runoff. The study also showed higher concentrations of copper, iron, manganese, and zinc in the green roof runoff than in that of asphalt roofs.

When considering runoff quality, it is critical to compare green roof runoff with runoff from black and white roofs. It is also important to consider whether the stormwater discharges to a combined sewer system or to a separately sewered stormwater system and whether the

Figure 15: Sloped green roof with sedums and other plants

body of water that ultimately receives the runoff is low in nitrates or phosphorous, in which case the addition of these chemicals may not be seen as polluting.

ACIDITY

Acid rain (defined as precipitation with a pH below 5.6), which is caused by air pollution, can damage buildings and harm ponds and lakes. The growth medium on green roofs can neutralize the acid in acid rain, because the growth medium itself is typically basic, with a pH from 7 to 8. The roofs seem capable of neutralizing acid rain in this way for 10 years or more, because the medium is well buffered, i.e., capable of absorbing and neutralizing acids. This feature of green roofs could be a significant benefit in areas such as the Northeast US, where acid rain is common. Runoff from a green roof generally has a pH above 6.5.

In Washington DC

The Casey Trees Endowment Fund Study used a model developed by Limno-Tech Inc. to analyze the effects green roofs can have on stormwater flows in Washington DC. The city is subject to combined sewer overflows during heavy rainfalls, which can lead to the flow of untreated sewage into the Anacostia and Potomac rivers and Rock Creek.

The study found that an extensive green roof can reduce runoff volumes by about 65%, and intensive green roofs by about 85%. The study considered the effect of installing green roofs on all “green roof-ready” buildings in Washington DC, which included about 75 million square feet of rooftop area. Using a ratio of 80% extensive roofs to 20% intensive roofs, it found that such an installation program would decrease roof runoff volume by up to 69% as compared with conventional roofing on the same buildings.

2.1.4 Economic Analysis

GREEN ROOFS IN CONTEXT

Are green roofs a cost-effective solution to stormwater management? Depending on local stormwater regulations and incentives, they can contribute to cost-avoidance for both building owners and municipalities. Green roofs should be evaluated in comparison with other measures designed to reduce stormwater runoff and combined sewer overflows, as part of a holistic review of the infrastructure. Other possible stormwater management measures include bioretention basins, permeable pavement, and infiltration chambers.

The costs and benefits of green roofs as compared with other stormwater management tools may depend on the objectives of a particular project.

Green roofs are recognized for their ability to mimic natural hydrological processes as part of a watershed management approach to drainage, in which a coordinated framework for environmental management focuses public and private efforts on the highest priority problems within hydrologically-defined geographic areas, or watersheds, taking into consideration both ground and surface water flow.

Table 4 describes other low-impact development water retention measures used at the ground-level like filter strips, bioretention basins and permeable pavements that can be used in place of or in conjunction with green roofs as part of an overall green infrastructure strategy or CSO/stormwater runoff mitigation scheme. These tools are only useful when the prepared sub-grade soil sustains a percolation rate of at least 1 inch per hour, when the underlying geology and topography are suitable, and where the soil is not contaminated. In addition, these alternatives typically require a large area to retain the water.

Technologies such as infiltration chambers and cisterns can also be used to satisfy stormwater retention requirements (Table 4). Infiltration chambers use rigid arches or rectangular galleries installed in trenches and backfilled with coarse stones. They can be used where space is limited or where stormwater management measures must be installed under paved areas. Compared to structural stormwater measures, implementing LID's can reduce costs by approximately 15 to 80 percent, according to research by the USEPA.

Cisterns can be used in areas where stormwater does not percolate into the soil, and where the water collected will be put to use in irrigation, for toilet flushing or in other ways. The typical capital costs of structural BMPs (including installing pumps and control systems to support these other systems) and LID BMPs are less than green roof per volume of stormwater.

For purposes of the cost-benefit analysis (see *Section* 3), the costs avoided to the owner by installing a green roof versus a conventional roof were $4.15 per square foot of roof nationally and $4.77 in Washington DC. These were only applied in Year 1 under the idea that regulation would require stormwater management during a major renovation such as installing a new roof. The maintenance for such systems was found to be $0.14 per square foot of roof per year.

PUBLIC INFRASTRUCTURE

Installing a green roof can help reduce wastewater treatment costs in areas with combined sewers, by reducing the volume of runoff and slowing its flow, thereby reducing the frequency of CSO events.

Table 4: Best Management Practices (BMP) to retain stormwater and/or reduce runoff

LOW-IMPACT DEVELOPMENT	STRUCTURAL
Bioretention	Infiltration chambers
Infiltration basins	Cisterns (external to building)
Permeable pavement	Cisterns (inside)

In communities where combined sewer overflows are a problem, the cost of treating stormwater as wastewater typically accrues to the taxpayer or rate payer. In the Washington DC area, it costs about $615 per million gallons to treat stormwater as wastewater. These costs are mainly due to additional pumping and treatment expenses at the Blue Plains Wastewater Treatment Plant. A study by the Casey Tree Foundation in the Washington DC combined sewer area concluded that if trees, tree boxes, and green roofs are installed throughout the combined sewer area, the District of Columbia Water and Sewer Authority (DCWASA) could potentially have an annual operational savings of $1.4–$5.1 million per year due to reduced pumping and treatment costs.

GREEN ROOF REGULATION FEES

For the purposes of the cost-benefit analysis, annual savings were based on regulatory fees charged at a rate based on the amount of impervious surface, with green roofs not counting as impervious. Green roofs were found to provide annual savings of $0.084 per square foot nationally and $0.078 per square foot in Washington DC, as compared with a conventional roof. A detailed discussion on stormwater regulation follows this section. However, Washington DC regulations would not generate any additional discounts for green roofs versus conventional roofs given the hypothetical projects that fully comply by using green roofs and/or BMPs. Therefore only the avoided stormwater costs discussed earlier were applied to the Washington DC cost-benefit analysis.

Stormwater Regulation and Policy in Washington DC

In urban areas with high-density development, green roofs may be the only practical way to address wet weather flows, especially where retrofit measures are required. Various requirements (federal, state, and local) drive stormwater management regulations. Green roofs are one way to comply (or help comply) with these regulations. Cities are offering green roof incentives and/or imposing fees regarding site stormwater management. The District of Columbia is an example of a jurisdiction that actively incentivizes the installation of green roofs. This Case Study provides an analysis of the stormwater management regulations of Washington DC and the federal government as they relate to green roofs.

INCENTIVES AND FEES

In Washington DC, the District Department of the Environment (DDOE) offers a green roof grant worth up to $5 per square foot, with a cap of $25,000 for qualifying projects, though the cap does not apply for retrofits of existing buildings. This grant, administered through local, non-profit partners, may also be available to non-federal buildings leased by the federal government, though buildings owned by the GSA and other federal agencies are not eligible.

A new amendment to the Federal Water Pollution Control Act (P.L. 111-378) expanded the types of state and local assessments (whether denominated as fees or taxes) associated with stormwater control for which federal agencies are responsible. As a result of this change in law, according to an opinion issued by the US Department of Justice's Office of Legal Counsel (25 February 2011), both types of stormwater assessments imposed by the District of Columbia are now payable by federal agencies:

- The assessment to offset the costs of constructing an enhanced combined sewage/stormwater system for the District of Columbia and
- The assessment to offset the costs of managing stormwater runoff regardless of its pathway to the receiving streams of the District of Columbia

In addition to regular sewer usage fees, these two assessments are calculated based on the amount of impervious area a property owner owns, with non-residential customers charged $3.45 per month per equivalent residential unit (ERU). One ERU equals 1,000 square feet, and the fee is rounded down to the nearest 100 square feet.†

ANALYSIS OF FEDERAL AND LOCAL REGULATIONS

Section 438 of the 2007 Energy Independence and Security Act (EISA) requires all new federal developments and re-development projects with more than 5,000 square feet of affected land to maintain or restore pre-development hydrology to the **greatest extent technically feasible**, through **infiltration, evapotranspiration** or **reuse on-site**, among other methods.

GSA's implementation of Section 438, and its application of U.S. EPA's 2009 Technical Guidance, will be achieved with due consideration of the District's standards. In that regard, it is anticipated that the District will be publishing regulations in 2011 that will clarify how it intends to work with federal agencies in the District, as these agencies implement EISA Section 438. The district is expected to take a flexible approach to satisfying the law that makes compliance more practical and affordable. Experts anticipate that the District will consider sites to be compliant with the law provided that LID BMPs have a combined interception volume equal to the design rainfall event, and that sites demonstrating higher interception volumes may receive Retention Credits that can be sold or traded.‡

The Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects defines the pre-development condition as the green-field undeveloped condition, and offers two options for complying with EISA Section 438.

Option 1: Retain rainfall associated with the 95th percentile rainfall event
Rainfall depth is calculated from historical data. In Washington, DC, the 95th percentile rainfall event is 1.7 inches. Runoff volume for a particular plot can be calculated using an approved analysis method.

The **EISA Section 438 Technical Guidance Document** recommends the use of green roofs, though it omits any discussion on how green roofs or any other best management practices contribute to satisfying the stormwater requirement. The guidance document implicitly treats green roofs differently from other best management practices.

Option 2: Conduct a site-specific hydrologic analysis using a continuous model simulation and implement a design that will preserve or restore pre-development runoff characteristics.

The advantage of this approach is that it recognizes the contribution a green roof can make toward modifying the overall hydrology of a site by reducing runoff rates and volumes through evapotranspiration,

† At the time of the study, legislation was being drafted that would let customers reduce this fee by managing stormwater and reducing impervious area. However specific details about the reduction were not available.

‡ Individual practices in the retention credit market will be capped at a volume of 1.7”. Projects required to comply with EISA may not qualify as retention credit sites but Federal sites can buy retention credits to comply when sites have retention deficits.

and by slowing the release of runoff.

In this option, continuous simulation modeling determines the runoff quantity, rate and duration of a site.

See the 2009 Technical Guidance for exclusions to EISA Section 438 that are recognized by US EPA.

In the case of the District of Columbia, all sites must meet the minimum standards in EISA Section 438. At challenging sites, the balance of the requirement can be met through offsite mitigation, which must be accomplished as retrofits to existing structures, or a fee in lieu (documentation of why the site did not meet the retention requirements is also required).

DDOE District of Columbia Storm Water Management Regulations (1988)

In addition to the stormwater management requirements set forth by the Energy Independence and Security Act of 2007, federal projects must comply with the various long-existent federal, state and local stormwater standards that emanate from the Federal Water Pollution Control Act. In this case the DDOE regulates stormwater compliance and offers guidance for compliance in their Stormwater Guidebook. Currently, DDOE has two requirements that are typical of many municipal stormwater regulations across the country, and which will be retained in the new regulation: rate reduction and volume reduction. Volume reduction requirements state that the Water Quality Volume (WQV) must be treated with an appropriate BMP. At present the WQV is equal to the first 0.5 inch of water collected from parking lots and 0.3 inch collected from all rooftops and sidewalks. Green roofs are not specifically mentioned as appropriate BMPs, however they are currently used as water quality BMPs in practice; the ability of a green roof to satisfy water quality requirements depends on the ability of the growth medium to detain the WQV in voids. Conversations with DDOE staff indicate that their regulation will be updated in mid-2011, and will more closely reflect the US EPA requirements for Federal Buildings discussed above, with a WQV associated with the 90th percentile event (1.2 inches) for private developments and the 95th percentile event (1.7 inches) for public projects.

The rate reduction requirement states that runoff rates for specified storm events shall not exceed runoff rates associated with a meadow in good condition. Specified events are the 2- and 15-year 24-hour storms with a type II (NRCS) rainfall distribution pattern. Antecedent moisture conditions are not specified. Green roofs contribute toward satisfying rate reduction requirements by lowering the overall site runoff curve number or rate coefficient, and lengthening the time of concentration for green roof areas.

‡In the revised regulations the WQV will not be included. The regulation will be limited to the retention standard of 1.2 inches and the flood protection requirements for the 2-year and 15-year rain events.

2.2 GREEN ROOFS AND BIODIVERSITY AND HABITAT

The term "biodiversity" refers to the variety of plants and animals in an area. A region is considered to have high biodiversity if it contains many different species, and enough individuals of each species to maintain a viable population size over the years. Increased biodiversity helps ecosystems to continue to function even when they are disturbed by development or in other ways.

Green roofs can provide new habitat for plants and animals in urban areas, increasing local biodiversity. Vegetation type, growing medium depth and variation in plant height and spacing are the three most important factors in encouraging biodiversity on a green roof. Studies suggest that the depth, topography, plant composition and age of a green roof, as well as the local landscape, can affect a roof's ability to enhance biodiversity.

In addition, design components that promote biodiversity may also help a roof improve performance on other criteria like reducing stormwater runoff and lowering summer surface temperatures. Reductions in summer surface temperatures have also been identified in comparisons between ranges of different vegetation types.

Key findings:

- Green roofs are found to attract species including birds and invertebrates
- The type of vegetation used is the most important factor in a green roof's ability to encourage biodiversity
- Growing medium depth and variation in plant height and spacing also affect biodiversity
- Intensive roofs typically support a greater diversity of rare bird species than extensive roofs

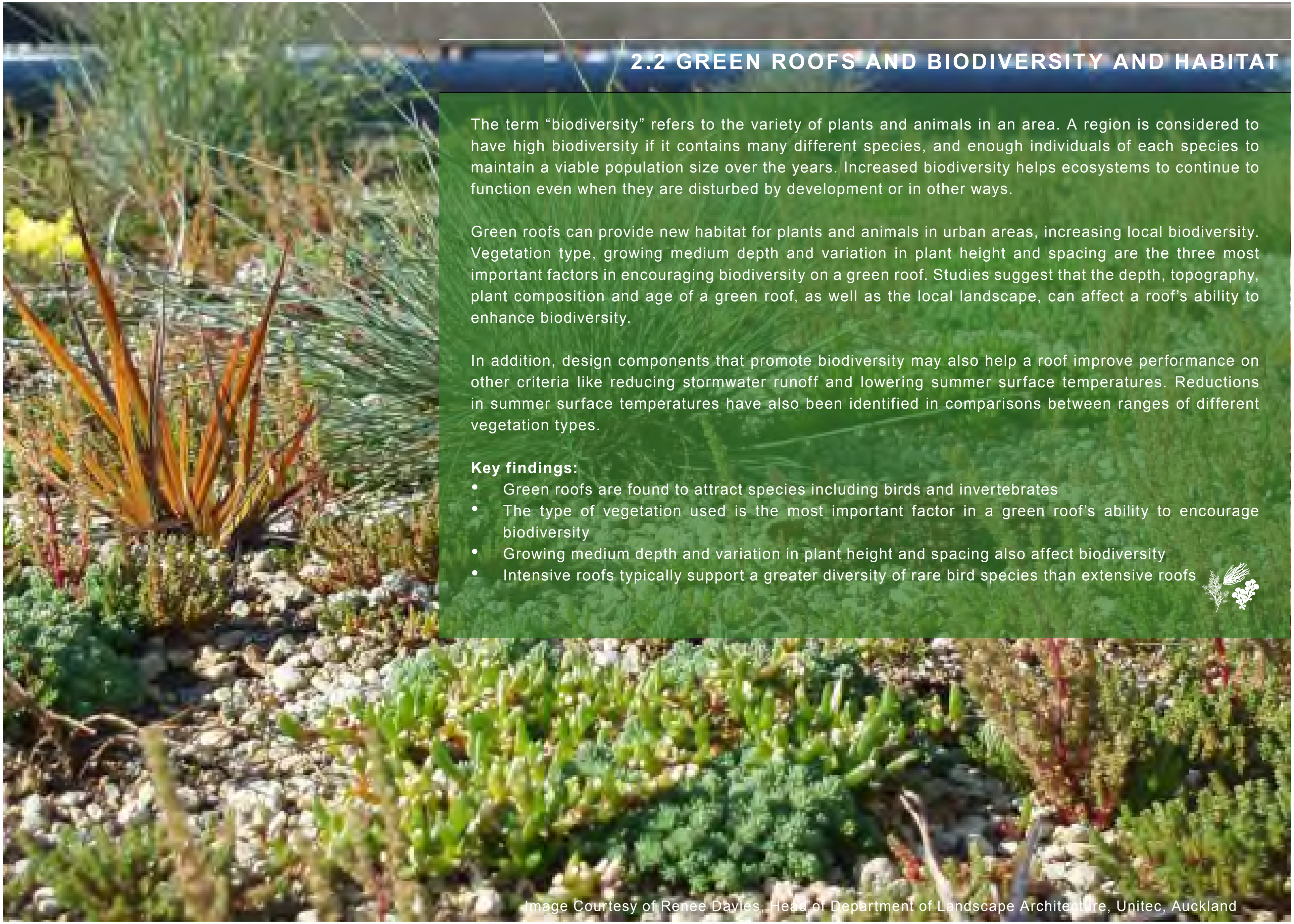


Image Courtesy of Renee Davies, Head of Department of Landscape Architecture, Unitec, Auckland

2.2.1 Introduction

Diversity of plant and animal species can make an ecosystem more resilient. Green roofs can encourage biodiversity by providing new habitat for plants and animals in an urban area. They can attract native plants and animals, as well as migrating birds.

The type of vegetation used is the primary factor in a green roof's ability to encourage biodiversity.

Some of the measures that enhance biodiversity on green roofs also create new design requirements that must be addressed for a roof to succeed. To mimic a wetland environment, for example, a roof must be designed to hold a limited additional amount of water, which requires careful modifications to the structural, waterproofing and drainage design. If deeper medium areas with larger vegetation are to be accommodated, the structural design must be tailored to suit the needs of the green roof.

The green roof of the California Academy of Sciences in San Francisco includes food sources for adult and juvenile Bay Checkerspot butterflies, an endangered species.

Figure 16: California Academy of Sciences green roof

2.2.2 Design and Management for Biodiversity

The three most important factors in encouraging biodiversity on a green roof are:

- vegetation type,
- growing medium depth, and
- variation in plant height and spacing.

The **plant layer** of a green roof is the main way designers can promote biodiversity. In general, an intensive roof with a mix of plant types and a varied composition may outperform an intensive monoculture roof of uniform height in terms of increasing biodiversity. Experts disagree on whether it is better to use native or imported species when planting a roof, though both types can serve particular purposes. **Native plants** may be harder to establish on a green roof but may be more successful in the long run.

In addition, variations in the growing medium can allow a green roof to contribute to biodiversity. Designers can create a series of diverse habitats on a roof by varying the depth of the rooftop soil. Deeper medium provides a potential habitat for a greater number of plants and animals than thinner medium. Shallow and deep roofs can be designed to simulate a range of environments from forest understory to ravine.

Green roofs provide permanent habitats for some insects and plants, and possibly birds and other animals. Designers can tweak a roof to provide habitat and food for breeding birds and their chicks, sometimes going so far as to target a specific species using careful analysis, design and monitoring. For example, an urban extensive green roof was designed to attract Lapwing (*Vanellinae*) and Plover (*Charadriinae*) using plants like moss, grasses and herbs that both species of bird prefer in their habitats.

Any green roof can become a nesting site, so designers need to consider providing options for water and shelter to boost the survival chances of chicks hatched on the roof.

Green roofs may support a substantial and diverse population of invertebrates like spiders, beetles, wasps and bees as observed in the United Kingdom and Switzerland. A variety of sedums with two or three other species can attract honeybees to a roof. Spiders can be a sign of good ecological function, as structural diversity to provide moisture and shade, and a steady supply of prey insects are needed to establish a sustainable community. Butterflies, a useful indicator of biodiversity, are also found on green roofs. Planting a roof with species that can be food for butterflies and insects can boost their populations. For example, the green roof of the California Academy of Sciences in San Francisco includes food sources for adult and juvenile Bay Checkerspot butterflies, an endangered species.

VEGETATION TYPE

The type of vegetation used is the most important factor in a green roof's ability to encourage biodiversity. Intensive roofs typically support a greater diversity of rare spider and bird species than extensive roofs, which are generally visited by more common bird species. Both types of roof attract a similar number of insect species.

An important consideration in planting a green roof is deciding whether to use native or imported species, otherwise known as exotic plants. Some designers argue that green roofs composed

Figure 17: Bird on an extensive green roof

of native plants may be more successful than non-native ones because they require less fertilizer, maintenance and water. However, it can be difficult to establish native species on a roof because of specific habitat and water requirements.

The Habitat Template Approach to picking plants for a green roof identifies species that grow in environments similar to that of the roof. The method takes into account soil depth, available moisture, and wind. Experiments throughout North America have shown that this approach can help native plants achieve a **cover value**, or a percentage of the terrain covered by plants, that is comparable to the best non-native species, with a high rate of survival and growth.

A roof that mimics a specific grade-level habitat could be colonized by rare native species based on observations in England and Switzerland. However, a roof may also be colonized by exotic species that originate in a habitat similar to the environment found on the roof. Prairie grassland is one of the few specific landscapes that have been recreated on green roofs in North America. Extensive green roofs can mimic dry meadow grassland through their minimal supply of nutrients, quick drainage and sun exposure.

Studies show that using plants that are common locally encourages speedy **colonization** of a roof by native insect species. Growing medium, spatial and vertical vegetation structure and the overall diversity of content on a roof are more important than the specific species used when it comes to colonization by certain insect species.

GROWING MEDIUM

Variations in growing medium can affect the ability of a green roof to promote biodiversity. Deeper growing medium provides a potential habitat for a greater number of plants and animals because of its increased ability to hold water and nutrients and its ability to accommodate plants with deeper roots. The shallow growth medium commonly used in extensive green roofs is less effective, as it intensifies the already extreme rooftop environment. Tolerant pioneer species may grow there, in addition to native plants that find in green roofs a refuge from common invasive species such as thistle and buckhorn, which have a hard time growing there (as observed on green roofs in London). Alvars and mineral ferns also grow on these roofs, which are similar to their native landscapes.

Designers can create a series of microclimates and **diverse habitats** on a roof by varying the depth of the growth medium. Shallow and deep roofs can be designed to simulate a range of environments from forest understory or ravine to riverbank or wetland, and many others.

Using natural, local growing medium that mimics local environments can create habitat by promoting the survival of native plants, which are already adapted to that particular soil environment. For example, in urban environments featuring existing landscapes like abandoned industrial sites at ground level, existing growing mediums may be used for green roof design to extend the available habitat for flora and invertebrates adapted to these environments.

STRUCTURAL DIVERSITY

Creating structural diversity through the use of a varied composition, abundance and spacing of plants is a third way to encourage biodiversity on a green roof.

> While limited by a roof's size and load-bearing capacity, designers can create green roofs that provide a range of structural complexity that mimics natural habitats. Creating a variety of microhabitats is one way to boost biodiversity on a green roof.

Rooftop features like parapets, equipment for heating, ventilation and air conditioning, and solar panels

Figure 18: Bee on an extensive green roof

contribute to the complexity of a green roof. Building systems create shaded, damp areas that can increase the diversity of a roof's population of invertebrates.

Designers may purposely create microclimates by adding branches, stones, sand piles and rubble to a green roof. Branches can be used to encourage birds to rest, and structures like bird and bat boxes can be used to encourage animals to nest and breed on a roof.

An intensive roof with a mix of plant types and variations in depth and surface structure may outperform an intensive monoculture roof of uniform height in terms of increasing biodiversity. Such roofs also produce a greater reduction of stormwater runoff and summer surface temperatures, as observed on green roofs in Halifax, Canada and Toronto, Canada. Plants like sedums with lower evapotranspiration rates have a smaller effect on reducing summer surface temperatures than other vegetation types.

MATURITY AND STAGING

Green roofs show greater biodiversity as they get older. Growth medium degrades over time, as does natural terrain. Over time, growth medium will lose bulk, gain organic matter, and show a greater abundance of a wider variety of species.

2.2.3 Economic Analysis

A green roof's contribution to biodiversity is difficult to measure economically. One way to measure the value of biodiversity on a roof is to compare the value it adds to the overall diversity of an area with that of a wildlife corridor or open space. In practice, regulators, investors and building occupants determine the value of green roof biodiversity, and the way in which biodiversity contributes to their sustainability goals. The green roof requirements of certain Swiss cantons, or states, were motivated predominantly by the desire to protect (and reintroduce) biodiversity.[*]

Governments and organizations are working to develop ways to measure the financial value of a natural ecosystem. For example, Australia's BushBroker scheme provides credits for "pre-vegetating" previously cleared areas like impervious urban sites with native species.[†] The price of a credit under this scheme ranges from US$0.42–$1.46 per square foot ($42,000 to $157,000/hectare), and is applied once over a 10-year period. In the United States, a biodiversity banking system exists to protect threatened or endangered species.[‡] The sale price for these credits averages approximately $0.41 per square foot.[§] Pollination by bees attracted to green roofs of flowers and crops is another potential benefit of economic importance.

[*] To attract animal species, specific medium and plant species types are required.

[†] The agreement requires a management plan for a 10-year period with annual reporting in perpetuity.

[‡] Conservation Banking Agreement requires third party oversight.

[§] The BushBroker scheme and the Biodiversity banking system are typically meant for large banks of land and may not be applicable to green roofs.

2.3 GREEN ROOFS AND URBAN HEAT ISLANDS

Urban Heat Islands (UHI) refers to the effect whereby near-surface air temperatures are higher in cities than in nearby suburban or rural areas. This effect is common in cities where natural landscapes, which absorb a significant portion of solar radiation to create water vapor, have been replaced with non-reflective surfaces that absorb most of the solar radiation and re-radiate back into the environment as heat. Heat islands cause increased energy consumption, heat-related illness and death, and increased air pollution.

Heat islands can cause heat-related illness and mortality, particularly during heat waves, which amplify the heat island effect. Prolonged exposure to high temperatures can cause heat cramps, heat exhaustion, heat stroke, heat syncope, and death. Heat exposure may also exacerbate cardiovascular illness, diabetes, and respiratory disease. Health impacts of the heat island effect are expected to worsen with climate change.

Green roofs can reduce the urban heat island effect by reducing temperatures and cooling buildings through the natural functions of plants.

Key findings:

- Heat islands increase energy consumption and can cause heat-related illness and mortality
- Plants can help mitigate the heat island effect common to the urban environment
- Green roof surface temperatures are cooler than black surface temperatures in all summer studies
- Evaporation and transpiration by plants play a key role in cooling green roofs

2.3.1 Introduction

Reintroducing vegetation on roofs is one of the most promising solutions to the problem of urban heat islands, as plants can help mitigate the heat island effect common to the urban environment. Green roofs also reduce summer air temperatures directly above the roof, making them more habitable and energy efficient.

Green roofs can influence heat islands in the following ways:

- By increasing the amount of solar energy that is reflected rather than absorbed
- By warming up more slowly in sunlight than conventional roofs
- By cooling buildings through the natural processes of plants

A green roof program covering 50% or more of roof space in a city, when implemented in coordination with other large-scale greening efforts like street tree planting, could result in city-wide cooling throughout the day and during peak summertime energy demand periods.

Heat islands may be observed adjacent to the building and infrastructure surfaces (e.g., roofs and roads), in the canopy layer—extending from ground level to the top of buildings, and in the boundary layer—extending from the top of buildings upwards to a height of 0.6 miles (1 kilometer) or more. In some cities the heat island effect, as measured by air temperatures relative to surrounding non-urban areas, is greater at night than during the day.

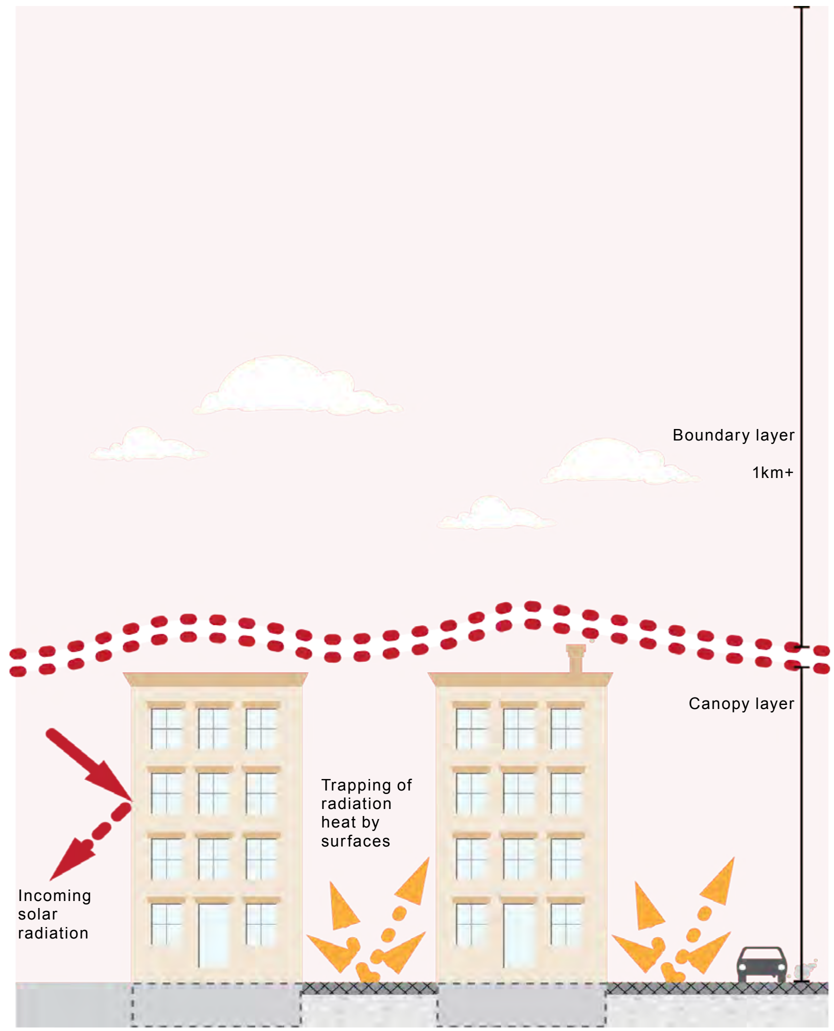


Figure 19: Urban Heat Island effects

2.3.2 Analysis

Green roofs have very different properties from conventional and white roofs in the context of urban heat islands.

PROPERTIES OF VEGETATION VERSUS IMPERVIOUS SURFACES

Evapotranspiration by plants plays a key role in transferring heat away from the surface on which the plants are growing. As water evaporates, it absorbs **latent heat**, which is energy used to convert matter from one phase to another, such as from a liquid to a gas. Through evapotranspiration, plants can use up to half the solar energy that hits a surface to convert liquid water in their leaves into water vapor they release to the atmosphere.

This process keeps some of the sunlight from contributing to raising the temperature of the roof, thus reducing surface temperatures and ambient temperatures above the roof's surface. Later, the heat is released in the troposphere as the water re-condenses, creating a "latent heat flux" from the ground upwards. The absence of this natural cooling in urban areas without plants is one of the greatest contributions to the heat island effect.

This cooling effect can create benefits in other areas. For example, the voltage produced by a solar panel falls as its temperature increases, so solar panels on a cooler roof will produce more power than those on a hotter one. This means that solar panels can operate more efficiently on a green roof than they do on a conventional roof, which heats up more in the sun. The electricial output of solar panels on green roofs in Berlin, Germany, and Portland OR, has been observed to increase by up to 6%; evidence that these technologies can co-exist.

PROPERTIES OF VEGETATION VERSUS BUILDING MATERIALS

Studies show green roofs have lower temperatures than conventional roofs (approximately 30 to 40ºF). Concrete and asphalt absorb, store and emit more solar energy than plants do, altering the surface energy balance in urban areas in two primary ways:

- **Albedo** is a measure of how much light a surface reflects. Albedo values range from 0 for a perfectly absorbing surface to 1 for a perfectly reflecting surface. Darker surfaces have lower albedos and absorb more light than lighter-colored surfaces. They may conduct heat into a building, raising indoor air temperatures, or they may absorb and then release heat, raising ambient air temperatures. The extent of these effects depends on the material.

- **Heat capacity** measures the amount of thermal energy needed to raise the temperature of a material. Concrete, asphalt and brick have high heat capacities, meaning they store greater amounts of heat energy as their temperatures increase during the day. When they release it at night, this energy contributes to the urban heat island effect.

Green roofs and urban forestry can reduce the area of low reflectivity and high heat capacity surfaces in an area, thus reducing the heat island effect. In addition, the vegetative cover on green roofs increases shading, which helps cool buildings.

It is difficult to measure the impact of green roofs on UHI as no city has collected sufficient data on the heat island effect before beginning a campaign of green roof building. It is not clear

Heat islands increase air pollution by forming an inversion layer that inhibits the dispersion of air pollutants. Elevated air temperatures facilitate the production of ozone, a major component of photochemical smog. Increased concentrations of atmospheric ozone have been linked with increased rates of daily mortality and higher incidence of cardiovascular and respiratory mortality.

Dark materials like asphalt and tar have low albedo values, meaning they absorb a lot of sunlight. For example, 80-95% of solar radiation is absorbed by asphalt and transformed into heat energy. White roofs have higher albedo values, meaning they reflect more sunlight than asphalt and tar surfaces. Materials that have high albedo values are cooler in summer because they reflect more energy from the sun than materials with low albedo value. The green roofs ability to reduce urban heat island is not albedo dependent but based on transforming the absorbed sunlight into water vapor through evapotranspiration.

Table 5: Albedo for typical surfaces in cities

MATERIAL	ALBEDO VALUE
Brick	0.20-0.40
Roofing tiles	0.10-0.35
Concrete	0.10-0.35
Tar/gravel	0.08-0.18
Asphalt	0.05-0.20
White roofs	0.75-0.80+
Vegetation/green roof	0.25-0.30

that any city has yet built enough green roofs to reduce its heat island effect, though we can estimate how much coverage would be required to do so. Simulations suggest that the simultaneous use of green roofs and green walls is significantly more effective than the use of green roofs alone in reducing surface and ambient air temperatures in urban canyons and over rooftops. Green roofs can also enhance the cooling effect provided by other vegetation in the area.

Heat islands increase energy consumption because electricity use grows as building cooling requirements increase. Every 1.08°F (0.6°C) increase in air temperature can add 1.5–2.0% to peak demand for cooling.

In Washington DC
A recent NASA study found the summer land surface temperature in Northeastern cities was an average of 13°F to 16°F (7°C to 9°C) warmer than that of surrounding rural areas. A 2007 study found average night time temperatures increased the closer they were to the Federal Triangle area of Washington DC, and that this effect extended up to 37 miles (60 kilometers) away.

2.3.3 Economic Analysis

It is difficult to measure the cost-benefit of reducing heat islands at the building level. At the community level, the reduction in average and peak temperatures, heat-related illness and mortality and air pollution are all potential benefits of reducing the heat island effect, though they are also challenging to measure.

In Ontario, Canada for every 1.8ºF above 64ºF, electricity consumption increases by 4%. In Washington DC, local power savings from a 0.18ºF reduction in temperature is worth $600 for every kilowatt shaved from the peak load.

In the cost-benefit analysis contained in the report, the UHI impact was conservatively estimated to be 0.70% reduction in energy. This plus the peak load savings amounted to an annual savings of $0.23 per square foot of roof per year. This was accounted for as a community benefit, not an owner benefit.

2.4 ENERGY

Energy prices and greenhouse gas emissions are increasing as fossil fuel energy sources such as coal, oil and natural gas decline. Executive Order 13423 issued in January 2007, requires federal buildings to reduce their energy use by 3% per year, resulting in a 30% reduction in energy use by 2015. An energy conservation measure like green roofs may help federal government facilities meet this target, and help other commercial buildings reduce their energy use.

Green roofs can reduce the amount of energy a building uses for cooling in the summer and heating in the winter. Green roofs can reduce the amount of heating from solar radiation a building experiences in the summer, and can insulate buildings, providing heat retention in the winter. The exact amount of energy saved depends on the climate, the type of roof and building, the height of the building and its neighbors, the amount of moisture on a roof, the variability of temperature changes throughout the day, and seasonal variations in temperature.

Key findings:

- Green roofs can reduce the amount of energy a building uses in summer and, to a lesser degree, winter
- Green roofs can reduce peak loads during the summer
- Evaporation from soil and transpiration by plants reduces the amount of heating from solar radiation a building experiences in the summer
- Green roofs insulate, shade and add thermal mass to buildings, providing heat retention in the winter and cooling in the summer
- Green roofs can moderate air temperatures immediately above the roof, which can be expected to lead to efficiencies at rooftop HVAC units
- The upper level floors show the greatest reductions in energy use

2.4.1 Introduction

The energy savings due to green roofs are strongly dependant on factors such as climate, type of roof, type of building, hourly temperature changes and the season.

During the summer, green roofs have a higher rate of evapotranspiration than conventional roofs made of impervious materials, creating a cooling effect on and around buildings, thus reducing the heat island effect, and reducing energy demand.

In both summer and winter, green roofs have an insulating effect on buildings, reducing peak heating and cooling demands in hot and cold seasons. This makes a smaller contribution to energy savings than the evapotranspiration effect.

The figure illustrates the main fluxes of energy at the roof surface. The soil layer of the green roof acts to reduce the heat conduction flux (in red). The plant canopy of the green roof exchanges with the shortwave and long-wave radiation (in yellow). Evapotranspiration (or latent heat loss) at the plant and soil layers reduce temperatures (in blue).

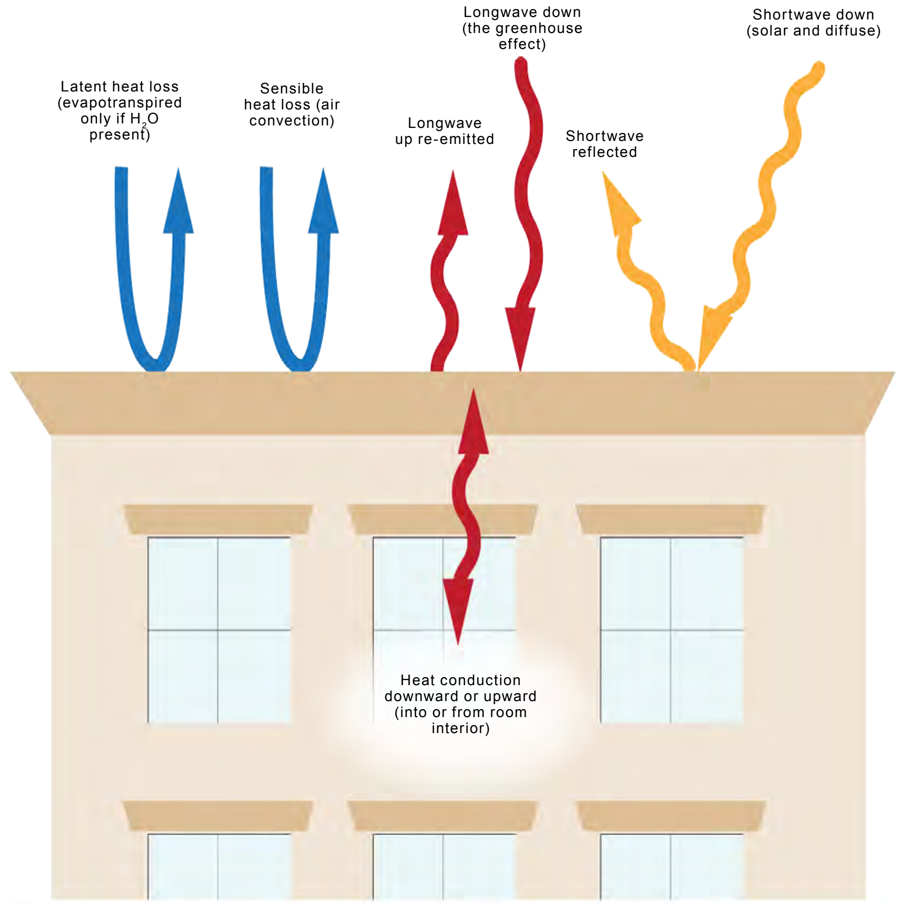


Figure 20: Surface energy balance for a roof

2.4.2 Analysis

SUMMER

Evapotranspiration creates a cooling effect on rooftops in summer. In the summer, the peak temperature of a roof's surface and membrane, and nearby air temperatures are lower on green roofs than on conventional roofs. Quantified results have been obtained for reduced surface temperatures in various climates such as Moscow, Russia, Riyadh, Saudi Arabia, Tokyo, Japan,Orlando, Florida, and Singapore.

Heat gain, the increase in building temperature due to solar radiation and high outdoor temperatures, is significantly lower on green roofs than black roofs**.** The thermal heat gain by a green roof can be up to 84% lower than that of a black roof. **Heat flux**, or the transfer of heat into or out of a building through the roof, can be reduced by as much as 72% compared to a black roof**.** Lower surface temperatures reduce **thermal loading** during the summer and reduce the amount of energy needed to cool a building. Deeper growing medium can enhance this effect, due to the greater insulating effect of the thicker growing medium and the additional thermal mass of the medium. Shading from plants can also enhance this benefit by reducing the amount of solar radiation that reaches the growing medium. A green roof on a three-story building in Japan was found to reduce the amount of energy needed to cool the top floor of a three-story building by 21 times.

Green roofs take longer to heat up and cool than conventional roofs, because of their **higher heat capacity (thermal mass)**. This reduces deterioration of roof membranes over time, and is one reason why green roofs last four times longer than conventional ones. The membrane of a green roof reaches its peak temperature several hours after that of a conventional roof. This "thermal lag" leads to a reduced mid-day peak heat gain as well as to warmer nighttime temperatures for green roofs, which can benefit buildings occupied 24-hours a day.

The specific components of a roof may also affect its performance. Light-colored rocks, porous aggregates, and certain plant species like *Sedum spurium* and *Sedum kamtschaticum* can be used to maximize temperature reductions throughout the year. In addition, climate plays a role. The evaporative cooling effect of irrigated green roofs is more pronounced in dry climates than in humid ones.

WINTER

Studies show that green roofs also outperform conventional roofs in the winter (though to a lesser degree than in summer), leading to energy savings from 13% to 33% through higher thermal resistance, or a greater capacity to resist heat flow. Winter heat loss for green roofs is estimated to be 34% lower than for black roofs, with a similar savings effect for white roofs. In addition, the thermal lag can reduce the amount of energy needed to heat a building in the morning. These benefits depend on climate, wind and snow cover.*

Recent observations of a 75,000-square-foot commercial green roof in Chicago and simulations of similar green roofs in Chicago and in Houston show a reduced heat loss and reduced energy consumption in the winter compared to similar white roofs.

*Snow cover will add further insulation to the roof reducing the heat loss and the flux of temperature at the membrane.

YEAR-ROUND

Green roofs have lower surface temperatures and reduce building energy consumption year-round, though the effect varies by season. An 8-story building in Madrid, Spain reported a 1% annual reduction in energy use, with 0.5% savings in winter and 6% in summer. Higher floors showed greater reductions in energy use.

Heat flux has been shown to be lower on a green roof than a black one. This can reduce peak and daily cooling demands during the summer, and heating demand in the winter. The magnitude of the savings depends on climate zone, site characteristics and building design.

The reduction in energy demand potentially reduces **greenhouse gas emissions** by indirectly reducing the amount of fossil fuels required at the utility's power plant or at the building's heating/cooling energy source, assuming that the energy comes from fossil fuels

Many buildings have ventilation air intakes and/or cooling and heating equipment located on the roof. Limited studies have shown that the tempered environment above a green roof produces a notable shift in air temperature at the point of air intake for this equipment. This means that the equipment requires less energy to cool the building in summer and to heat it in winter. The savings potential from this effect may exceed that of direct heat flux reductions, but it requires more study.

Photovoltaics installed on the United States Environmental Protection Agency Region 8 Headquarters, Denver, Colorado

2.4.3 Economic Analysis

The local climate, energy costs, location, and building design are vital in potential building energy savings. The annual energy savings attributable to green roofs were found to be approximately $0.166 per square foot of green roof nationally and $0.169 in Washington DC (despite different energy prices).

As savings are mostly realized in the uppermost floors, the cost-benefit analysis assumed a particular height: 8-stories. As the size of the roof varied (5,000, 10,000, and 50,000 square feet), the degree of savings changed as the amount of space realizing savings changed. In the cost-benefit analysis, this was accounted for using a model generated by Centre for Environment at the University of Toronto. For a building with a 5,000 square foot roof, the average energy savings was $0.155 per square foot of roof while the 50,000 square foot roof building experienced a savings of $0.190 per square foot of roof. Savings will likely diminish with each additional floor.

Several green roof studies also included the savings from the reduction in rooftop heating and cooling equipment, though this report did not because heating and cooling equipment are not always located on the rooftop. The justification is that with a more stable thermal environment above the roof—one that is cooler when it is hot and warmer when it is cold—the building's equipment potentially runs more efficiently and lasts longer. These savings would apply equally to multi-story and single-story buildings. Additionally, if a green roof retrofit were to coincide with an HVAC upgrade, the internal heating and cooling savings could reduce demand and thus reduce the sizing of the upgraded equipment.

Green roofs may potentially reduce the amount of carbon dioxide and smog-causing pollutants emitted by power plants by reducing the peak and annual cooling and heating energy use in buildings through improved roof performance. Regulators, building occupants and investors all demand these reductions in energy related emissions.

2.5 URBAN AGRICULTURE

The current food production system relies on several resources such as water, soil, nutrients and energy. On average, Americans consume 300 gallons of oil annually for the sole purpose of food production. Using green roofs to grow food might reduce carbon emissions associated with food distribution.

Urban agriculture on rooftops potentially increases property values through an additional building service and added marketability. In addition, the roofs of office buildings are hard for vermin to reach, potentially protecting crops from damage by pests.

Depending on structural loads and accessibility, agriculture on green roofs could offer an outlet to educate urban residents about food production and seasonal variety, and may boost local gardening efforts. Rooftop farming could also help generate jobs.

Key findings:

- Green roof gardens with growth medium more than six inches deep (intensive) can support a variety of crops, however, herbs have grown on growth medium less than six inches deep
- Agricultural services like food, biofuel and nursery growth on a roof create potential economic and social benefits not available on conventional roofs
- Security is a potential issue with providing access to federal building roofs for agriculture

Image Courtesy of Sarah Khand

2.5.1 Introduction

Over the last few years, rooftop gardens and farms have been recognized as a promising form of urban agriculture, and a way to take advantage of a significant amount of flat space that receives steady sunlight throughout the day.

Using rooftop space for food production might help reduce the distance food travels to reach consumers, potentially reducing carbon emissions associated with food distribution. It could also provide fresh and local food options to building occupants and the local population. It could even provide an outlet to educate the local community about food production and seasonal variety. It could also boost property values through the addition of a new building service, and help create jobs.

Urban agriculture can appear in a variety of forms, such as container gardens, hydroponics, aquaponics, vertical farming, multi-tiered farming, technologies, apiculture, and rooftop gardens. This last form of urban agriculture, rooftop gardens, is one that can utilize available space over a somewhat limited environment.

2.5.2 Analysis

The success of a rooftop garden depends on rooftop access, maintenance needs, exposure to sun and wind, and the local climate. Local zoning may prohibit the use of rooftop space for urban agriculture, although such policies can be changed. For example, in 2010, the Seattle City Council adopted Council Bill 116907 to allow urban farms and gardens in all zones.

The load-bearing capacity of existing roofs is an important issue when considering urban agriculture. Rooftop farms and gardens typically have growth medium more than six inches deep, which can support a wide variety of crops. Some crops are difficult to grow without at least 18 inches of soil. Roofs with less than six inches of growth medium can support the growth of some herbs. Kale, spinach and lettuce crops have been grown on a modular green roof in Toronto, Canada with less than 3 inches of growing medium.

Farming is labor intensive, requiring continual attention to manage crop production and distribution. This may raise safety and liability issues as compared with a low-maintenance green roof.

For federal buildings, security is the major challenge to incorporating an urban farm in a green roof, if it were to be tended by non-federal workers. Background checks would likely be required, and roof accessibility and the accountability of metal gardening equipment would also create challenges.

The Pocket Habitat on a roof in Gloucestershire, England

2.5.3 Economic Analysis

A Toronto study estimated that using all the rooftop space in the city to grow crops could create a value return of CAN$1.7 billion. **Agricultural services** like food, biofuel and nursery growth create potential benefits from green roofs, though they are typically not seen on roofs with 3- or 6-inch growth medium. This was not accounted for in the cost-benefit model, due to the newness of urban agriculture and lack of usable data.

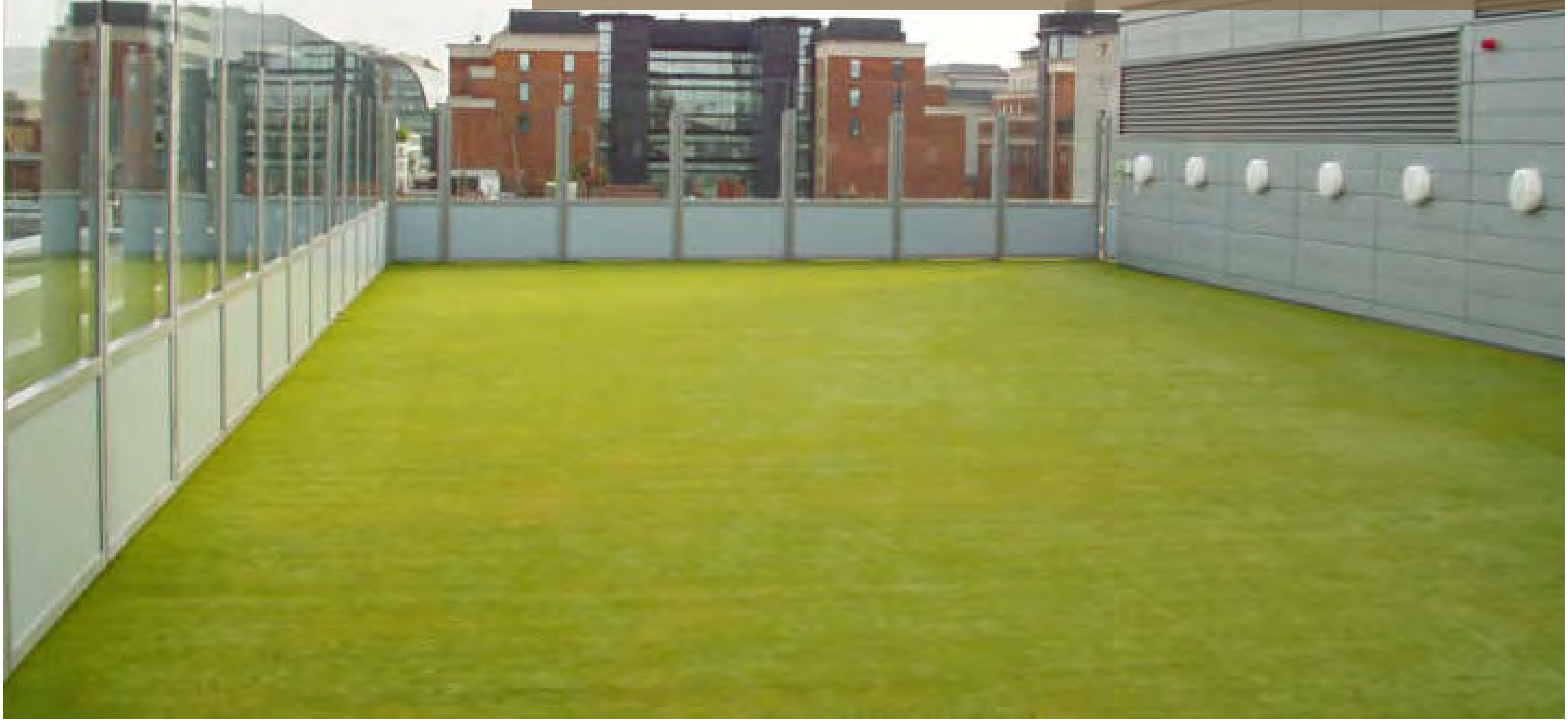
Rooftop gardens in London, England

2.6 ACOUSTICS

On a pound-for-pound basis, green roofs are better at noise reduction than traditional and concrete roofs. When used on buildings without sufficient ceiling insulation, green roofs can improve noise reduction on the upper levels, especially in areas with heavy motor or air traffic.

Key findings:

- Green roofs provide acoustic insulation
- The benefit of noise reduction by a green roof depends on the building's location, with those near highways or under areas of high air traffic receiving the greatest benefit
- The acoustic benefits of green roofs are greatest within the top floors of a building



2.6.1 Introduction

Green roofs can reduce noise pollution from airplanes, elevated transit and traffic, particularly for low- and medium-frequency waves. They have better noise reduction per unit of weight than traditional or concrete roofs. This reduction will primarily affect a building's top floor. Green roofs can enhance the attenuation of diffracted sound and reduce the transmission of sound through a buildings' roof, particularly in buildings without additional ceiling insulation.

2.6.2 Analysis

According to extensive studies, roofs 2 to 6 inches thick have reduced the noise level of a roof by 8 decibels or more, depending on the water content in the growing medium. The greater the proportion of a roof covered in green roofing, the greater the reduction in sound pressure from noises traveling across the roof. The weight of a roof determines the amount of insulation available to attenuate surrounding noise. The texture of growth medium can affect this attenuation. Green roofs have the potential to reduce both low frequency sounds (blocked by the growing medium) and high frequency sounds (blocked by the vegetation).

The growing medium, drainage layers, and vegetation determine the weight of a roof, and therefore the amount of insulation thereby available to attenuate surrounding noise.

2.6.3 Economic Analysis

The benefit of noise reduction by a green roof depends on the building's location, with those near highways or under areas of high air traffic receiving the greatest benefit. A 2004 study found that the potential savings to airport authorities in terms of the potential reduction of noise mitigation costs paid was $0.43 per square foot of green roof per year, though this savings depends on the local real estate market, and would likely be seen through a higher rental rate. This was not accounted for in the cost-benefit model.

2.7 AIR QUALITY

Plants have long been used in the urban environment to remove air pollutants and greenhouse gases like carbon dioxide, particulate matter, nitrogen dioxide, sulfur dioxide and carbon monoxide. Green roofs can reduce air pollution, depending on the types of plants and the soil depth.

A green roof could be used as a carbon sink in a cap-and-trade system, which provides a mandatory cap on carbon emissions.

Key findings:

- The vegetation on green roofs can absorb air pollutants
- The amount of carbon required to create and install a green roof is typically higher than the amount of carbon it can absorb but when energy savings are factored in, a green roof can be a net carbon sink

2.7.1 Introduction

Greenhouse gases are gases that trap heat in the atmosphere. A major greenhouse gas, **carbon dioxide (CO_2)** is emitted to the atmosphere through natural and anthropogenic processes. Carbon is sequestered in plants through photosynthesis, and it is stored in the soil and roots. At the end of the plants' lifetimes, carbon is released into the atmosphere as the plants decompose and the soil is disturbed.

Nitrogen-oxides (NOx) and **particulate matter (PM)** are the types of pollutants that can most easily be reduced through green roofs. Nitrogen- oxides are produced in combustion and create smog and acid rain. Plants remove gaseous pollution from the air through their pores, or stomates.

With the rise of industrialization and urbanization, pollution and waste treatments have introduced a significant amount of heavy metals into the environment. The annual release of heavy metals worldwide in 2003 reached 22,000 metric tons for cadmium, 939,000 metric tons for copper, 783,000 for lead, and 1,350,000 for zinc. Plant tissues absorb poly-aromatic hydrocarbons and heavy metals.

2.7.2 Analysis

Green roofs remove pollution from the air in several ways. Plant stomates absorb gaseous pollutants, the leaves intercept particulate matter, and plant tissues absorb poly-aromatic hydrocarbons and heavy metals. Furthermore, harmful ground-level ozone is reduced through the effect that vegetation has on air temperature cooling, and therefore photochemical reaction rates are reduced.

A green roof's ability to act as a carbon sink depends on the type of vegetation and the surrounding environment. The amount of carbon required to create and install a green roof typically exceeds the amount of carbon it can absorb.

Using the US Department of Energy's (USDOE) carbon offset projects, the embodied carbon needed to create a green roof was calculated to be 0.0006 metric tons of emissions per square foot, roughly equal to the heating and cooling emissions savings a typical green roof creates. The benefit of increased carbon sequestration and reflectivity is measured at 0.0002 metric tons per square foot with sequestration realizing the slightest of benefits of 30×10^{-8} metric tons per square foot.

Thicker growth medium or growth medium that includes expanded clays and shales* can allow a roof to sequester large amounts of carbon dioxide. Plants like large perennials can also increase a roof's ability to sequester carbon, while the application of fertilizer, composition of growth medium and irrigation can also have an effect.

A two-year study in Michigan on a 2.5 inch-thick extensive sedum roof showed a net carbon sequestration of 378 grams of carbon per square meter in the plant material, root biomass and growth medium.

*Expanded clays and shales have a high embodied energy due to the manufacturing process

2.7.3 Economic Analysis

In Washington DC
Air in Washington DC has high concentrations of ground-level ozone and particulate matter. Using a United States Department of Agriculture (USDA) Forest Service Urban Forest Effects model, the Casey Trees Endowment Fund Study evaluated the air quality benefits of a mixture of trees and vegetation in intensive and extensive green roofs in the city. The study considered the effect of installing green roofs on all "green roof-ready" buildings in the District, or about 75 million square feet of rooftop area. The model found that this 100% coverage scenario would remove about 58 metric tons of pollutants from the air, the equivalent of planting 85,000 to 115,000 trees. Under this scenario, particulate matter was the primary pollutant removed from the air, though sulfur dioxide, nitrogen dioxide and carbon monoxide were also removed.

In addition, some plants used in green roofs, like *Sedum album* and *Sedum spurium*, are metal hyperaccumulators, with unusually high intake and storage levels of elemental metals.

The reduction in nitrogen-oxide compounds by a green roof is calculated to be worth $0.0008 to $0.589 per square foot of green roof. The amount of nitrogen-oxides compounds taken up by a roof depends primarily on the type of vegetation used.

The nitrogen-oxide costs assume either costs for replacement or addition of equipment, such as a flue gas scrubbing system, or human benefit costs that were evaluated as part of an EPA study. This same logic could be used for Particulate Matter less than 10 micrometers (PM_{10}), sulfur-oxygen compounds and carbon monoxide, which would result in benefit of $0.00115 per square foot of green roof, $0.000002 per square foot of green roof, and $0.000096 per square foot of green roof, respectively.

In addition to pollutant capture, the report "Cool Communities: Strategies for Heat Island Mitigation and Smog Reduction" showed that there is a correlation between air quality and reduction in temperature (see *Section* 2.3 for more details). Specifically, the report states that for every 5.4°F (3°C) reduction in environmental temperature, nitrogen-oxides are reduced by 50 times with pollutant capture reductions. The cost-benefit analysis used a conservative (0.81°F or 0.45°C) reduction due to green roofs, which yielded a multiplication of NOx benefits by 7.5 times.

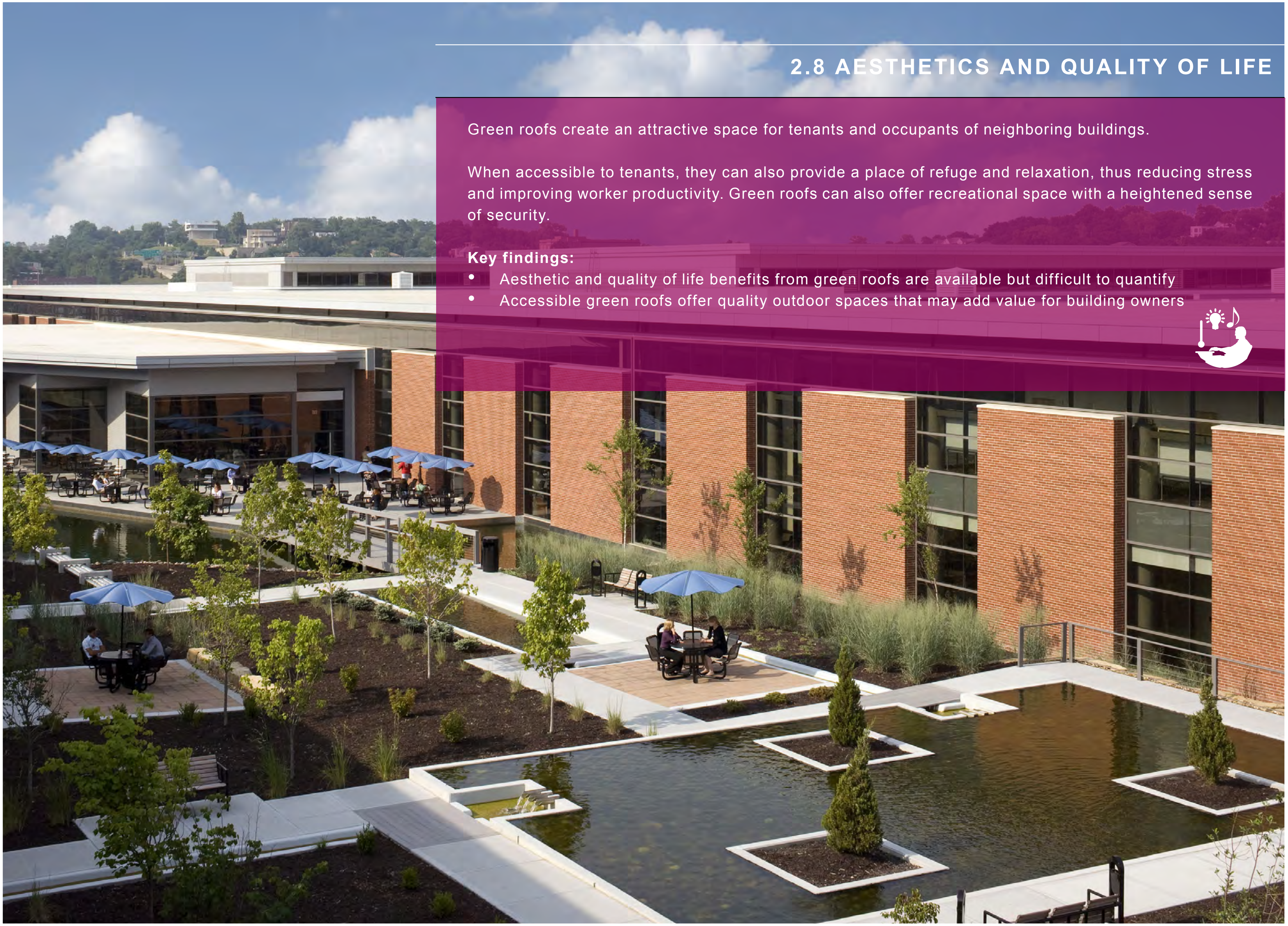
2.8 AESTHETICS AND QUALITY OF LIFE

Green roofs create an attractive space for tenants and occupants of neighboring buildings.

When accessible to tenants, they can also provide a place of refuge and relaxation, thus reducing stress and improving worker productivity. Green roofs can also offer recreational space with a heightened sense of security.

Key findings:

- Aesthetic and quality of life benefits from green roofs are available but difficult to quantify
- Accessible green roofs offer quality outdoor spaces that may add value for building owners



2.8.1 Introduction

Converting flat building roofs into recreational green space can benefit building occupants by providing a safe place to eat lunch and relax outside. Plants and natural surroundings have been found to reduce stress, lower blood pressure and increase satisfaction in users. Green roofs can also create an attractive space for occupants of neighboring buildings. In addition, green roofs have higher aesthetic value than structural infrastructure like catch basins and drainage pipes.

A case study of Alta Bates Medical Center in Berkeley CA, looked at the benefits of a rooftop garden for both patients and staff. Several people in the garden were interviewed as to what types of activities they engaged in on the roof and there were overall themes in the responses: relaxing, talking, eating, strolling, and "outdoor therapy." A brief escape from the demands of work would be beneficial to any GSA employee or GSA building occupant. Other research by Frances Kuo has shown that green space can reduce stress, decrease recovery time and diminish crime. Green roofs can provide some of these benefits.

2.8.2 Analysis

A green building with a green roof allows not only building occupants but users of nearby buildings views of and contact with the natural environment.

The height of parapets and the nature of other structural components will determine a green roof's effectiveness as an open or recreational space. Benches or seats are typically provided to create an amenity space for building occupants as part of a green roof. Adding windscreens to shield amenity areas can make a green roof more attractive to potential users.

Accessible roof at the John W. McCormack Post Office and Courthouse, Boston, Massachusetts

2.8.3 Economic Analysis

Aesthetics and quality of life are difficult to quantify, especially in regards to green roofs. Still, some research has found that green roofs can provide significant value to a building's owner and tenants through greater productivity and reduced absenteeism. They can also benefit the larger community through improved aesthetics and views of the green roof.

Although researchers have not addressed green roofs specifically, one study has shown the overall effect of green buildings to have a net present value of $12 per gross square foot in terms of greater productivity and lower absenteeism. Additional research has found that office workers are 2.9% more productive when the view out of their office windows includes vegetation.

Because these studies are not specifically related to green roofs and the methodology is open to debate, productivity, absenteeism, aesthetics, and views were not accounted for in the cost benefit analysis. The overall evidence, however, is that green roofs have the capacity to provide significant value in terms of productivity and absenteeism to the tenants (and thus the owner) as well as to the community at large who benefit from the improved aesthetics and views of the green roof.

Accessible green roof at the 10 West Jackson Street Building, Chicago, Illinois

2.9 JOB GENERATION AND ECONOMIC DEVELOPMENT

Green infrastructure is an “effective response to a variety of environmental challenges that is cost-effective, sustainable, and provides multiple desirable outcomes.” The green infrastructure movement provides opportunities for future employees, specifically unskilled labor, to develop marketable skills in the areas of landscaping and green roof maintenance.

A **green job** is one that plays a direct role improving the environment. These jobs should also be sustainable, providing workers long-term career opportunities.

Green roofs offer job opportunities for both skilled and unskilled workers. They also offer building owners more marketable buildings in comparison to those without green roofs.

Key findings:

- Green roofs can provide green job generation through the production, installation and maintenance of green roofs
- Green roofs can provide investment benefits for building developers and owners and provide marketing opportunities to the building

2.9.1 Introduction

Green roofs, which are considered green infrastructure, can create employment opportunities in production, installation, and maintenance of the roof.

Green roofs also can provide marketing opportunities and investment benefits for developers and buildings owners.

2.9.2 Analysis

In the US, employment from green roofs rose over 80% from 2004 to 2005. Green roofs can create a range of jobs including: suppliers and manufacturers of roof membranes, root repellent layers, drainage layers, landscaping fabrics and other materials; suppliers and manufacturers of growing medium, soil and soil amendments like compost, peat moss, or fertilizer; nurseries, especially organizations specializing in plants for green roofs; designers, engineers and roof contractors; and building contractors, maintenance contractors and engineers.

A market for jobs related to green roofs has existed in Germany since the introduction of FLL standards and some incentives in the 1980s. Researchers found that the German green roof industry has grown 15% to 20% a year since 1982, and has helped created jobs in the industries listed above.

A study found that green roof investment by the government over a one-year period could create from 600 to 1,800 jobs per year* in the Washington DC area (Table 6). Economists disagree about the actual employment potential resulting from incentives and government investment, and some believe that job gains related to green roofs would be offset by the loss of jobs related to conventional roofs. Even green roofs have some need of workers who specialize in conventional roofs, to install a membrane beneath the green roof.

Green Roofs for Healthy Cities (GRHC), a not-for-profit industry association, established the **Green Roof Professional** program in January 2007. The accreditation potentially enhances job opportunities in the green roof industry for professionals who

A 2009 study contracted through the Washington DC Office of Planning performed a job demand analysis regarding Green Collar Jobs. Part of the analysis included the jobs created by the green roof industry based on the amount of investment required. The analysis used the Casey Trees Endowment Fund Study, "Re-greening Washington DC: A Green Roof Vision Based on Quantifying Stormwater and Air Quality Benefits" as its basis.

Table 6: Green roof job generation in Washington DC

SCENARIO TYPE	JOBS CREATED PER YEAR (AVERAGE)	INVESTMENT (IN MILLIONS)
Pessimistic	590	$299.9
Conservative	1,179	$599.8
Aggressive	1,769	$899.6

*Estimates were made in 2006 and based on a direct investment over a 10 year period

In Washington DC

Non-profit organizations in the Washington DC area such as Casey Trees and DC Greenworks offer educational training in urban forestry and green roof maintenance. In addition, DC Greenworks also trains low-income residents in plant nursery work and landscaping.

1425 K Street NW is the first high-rise building in the District with a green roof. It was installed through a partnership between Casey Trees, DC Greenworks, Covenant House and Blake Real Estate, the building's owner and property manager. The roof was funded by grants from the DC Department of Health and the National Fish and Wildlife Foundation. In addition to serving as an amenity for workers in the office building, the roof is a demonstration project designed to increase public familiarity with, understanding of and support for green roofs.

understand the elements of green roof assembly, such as waterproofing, structural engineering, project and water management, growing medium, plants and maintenance. This occupational standard helps building developers, owners and designers identify landscape designers and contractors who understand the elements needed to install and maintain a green roof, potentially mitigating liabilities when compared with hiring inexperienced designers and contractors.

Reintroducing green space to an urban environment adds aesthetic value to nearby properties. Proximity to green space, in particular views of parks and tree cove, can boost the value of a building by up to 15%. A study of green roofs in Nuremberg, Germany, found that green roofs led to higher occupancy and higher rental rates, even during a real estate downturn. However, quantifying the benefits of green buildings—let alone green roofs—is challenging.

As with any building attribute, the realized value of a green roof depends on its effect on performance and the general recognition by the relative market. In the capitol region, both performance and market recognition are better understood; however, this study must still contend with the difficulties of attributing performance and recognition to a single component: a green roof.

2.9.3 Economic Analysis

Neither changes in employment and value (which would lead to increased tax revenue) were accounted for in the cost-benefit analysis. This is because the data is limited and the applicability extremely varied. However, the data does suggest that installing green roofs versus conventional roofs would lead to more jobs and higher property values.

A supplemental analysis was conducted to predict the market's valuation of a green roof. Average commercial rents, expenses, vacancy, discount rates, absorption, and lease lengths were identified and modified based on an expectation that, like green buildings, the market values green roofs.

An analysis to predict the market's valuation of a green roof estimated that they would have a **real estate effect** of **$13 per square foot of green roof nationally** and **$10 in the Washington DC** area. Net present value of 50 years of these savings amounted to $110 and $90 per square foot of roof, respectively. Data from real estate information provider Costar and the USGBC found that green buildings realize 5.7% more rent than conventional buildings nationwide, and 7.4% more rent in Washington DC.

Using average construction costs, green building premiums, and the premium costs of green roofs, it was assumed that green roofs account for 44% of the total green construction premium. Collectively, these two premiums suggest a rental premium of 2.5% nationally and 3.3% in Washington DC.[†]

[†] When considering the proportion of a green building premium attributable to green roofs, it is important to keep in mind that most green buildings (e.g., LEED certified) do not include a green roof. Most upgrades needed to earn green building credits add from 2-10% to the cost of a building, and involve substituting less-efficient equipment with higher-cost and higher-efficiency models. A green roof, in contrast, is an entirely new piece of equipment installed in addition to a conventional roofing layer.

2.10 ROOF LONGEVITY

Properly installed green roofs more than double the number of years before a roof needs to be replaced, as compared with conventional and white counterparts.

Key findings:

- Studies suggest that the average life expectancy of a green roof is 40 years, versus 17 for a conventional roof, however, numerous green roofs have outlived that time period
- A properly installed green roof will likely only need to be replaced if the membrane below has aged to the point where it needs repair

2.10.1 Introduction

The lifespan of a roof's membrane largely determines a roof's longevity. Properly installed green roofs more than double the number of years required before a roof needs to be replaced, as compared with conventional and white counterparts. This is because a green roof's vegetation layer and growing medium protect the roofing membrane from damaging UV radiation and from fluctuations in temperature extremes. Temperature fluctuations cause daily expansion and contraction in the membrane, wearing it out over time.

2.10.2 Analysis

Our study puts the average life expectancy of a green roof at 40 years versus 17 years for a black roof. The lifetimes of green roofs are difficult to predict because some do not need to be replaced even more than 50 years after installation. Green roofs installed on several federal buildings in the National Capital Region have not been replaced since their installation in the 1930s.

A green roof's soil and vegetative layers provide significant protection to its base layer, which is almost identical to that of a black or white roof. Soil and vegetation minimize the negative effects of exposure to UV rays, wind, water and mechanical damage (see *Section* 4.3.1 and *Section* 4.3.3 for leak and wind scour issues). Thermal mass and simple physical separation are mostly responsible for these benefits. Table 7 below illustrates the varying research relating to expected roof lifetimes:

Table 7: Green roof membrane lifetime versus conventional roof membrane lifetime

LIFETIME, YEARS	GREEN	BLACK
GRHC Life Cycle Cost Calculator	25	17
LBNL Research	29	14
Fraunhofer Institute	40	15
European Federation of Green Roof Associations	60	30
Mann, G. (2002) *Approaches to object-related cost-benefit analysis*.	50	25
Single Ply Systems & Glass, GAF Materials Corp, SBS/TPO average*	n/a	14
AOC Dirksen Green Roof Study	50	17

*The data represents an average. Actual costs can vary significantly depending on the building condition, the exact location (due to building codes etc), and the local labor rates.

2.10.3 Economic Analysis

The cost-benefit model used the previously mentioned 40-year lifespan for green roofs and 17-year estimated lifespan for conventional roofs.[†] *Section* 3 references the cost premium of green roofs compared to black roofs.

There is very little data regarding replacement of green roofs. Since green roofs prolong a membrane's lifetime, a properly installed green roof will likely only need to be replaced if the membrane has aged to the point where it needs repair. If this is the case, the green roof medium can be salvaged and stockpiled for reuse, and the vegetation can be replanted. However, the membrane layer will need to be disposed of in a landfill, as would a conventional roof after replacement. This study used a green roof replacement cost of 33.5% of the installation cost to account for the labor needed to remove the roof medium.

[†] Cost benefit analysis weighted the longevity of green roofs and black roofs using various studies (see Table 7)

GSA Region 8 - United States Environmental Protection Agency Region 8 Headquarters, Denver, Colorado

A 19,200 square foot accessible, extensive green roof installed on the new EPA headquarters (2006). Tests have shown an approximate 40% decrease in heat transmitted through the roof compared to the control roof (next door) and an approximate 85% stormwater retention rate for all ½-inch or less storm events. The green roof also reduced the size of the cistern in the basement, which allowed more space for parking.

GSA